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ASSESSMENT SOFTWARE FOR ATTENTION PROFILES

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We begin with a brief historical summary of the concepts associated with attention, followed by a review of existing factor analytic studies of attention and executive function, as well as summary of the commonalties, discrepancies, and idiosyncrasies found in this literature. Last we describe the battery of tests used in our research, the results including factor analysis and use of attention profiles of the factor to predict the outcome of a variety of criterion variables.

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ASSESSMENT SOFTWARE FOR ATTENTION PROFILES

Final Report[1]

The Factors of Attention

The experimental study of attention and related phenomena has resulted in an extended body of divergent phenomena which seem to be refractory to a simple explanatory theory (e.g., Pashler, 1996). Thus, the experimental approach seems to multiply phenomena and complexity without moving towards a comprehensive theoretical account of attention, if one could be formulated. However, there are a limited number of categories of attention related phenomena found within this diverse literature, which suggest some dimensions of attention. Following this line of thought, an alternative to the experimental approach is to explore possible dimensions of individual differences. This strategy is based on the assumption that there are a limited number of attention related abilities which could be tapped using an appropriately designed battery of tasks. The purpose of the present research was to pursue this strategy.

Although there are some studies in the literature which have been directed solely towards the identification of attention related abilities (e.g. Mirsky, 1987; Stankov, 1988), there are a number of others which are concerned with identifying various aspects of executive function (e.g. Shute and Huertas, 1990; Pennington, 1997). These two groups use many of the same tests in their batteries, suggesting that there ought to be some common conceptual basis underlying their respective factors.

We begin with a brief historical summary of the concepts associated with attention, followed by a review of existing factor analytic studies of attention and executive function, as well as summary of the commonalities, discrepancies, and idiosyncrasies found in this literature. Last we describe the battery of tests used in our research, the results including factor analysis and the use of attention profiles of the factors to predict the outcome of a variety of criterion variables.

Dimensions of attention

Although attention sounds like a singular term with a unitary concept as a referent, it has a remarkable history of meanings. Sixty years ago Spearman (1937) likened the psychological study of attention with the resultant proliferation of jargon to the building of the Tower of Babel. Sixty years later, as the range of usage of attention and its contexts are perused one can find the sort of variety found in Table 1. In addition attention has also been linked to a diverse group of seemingly incommensurate empirical phenomena such as the cocktail party effect, Stroop

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[1] This research report is submitted to complement the activity "final report" submitted for this project on in 1997. Although the report is final, analysis of these data and generation of follow-up studies continues.

interference, illusory conjunctions, the pop-out effect of visual search, and the psychological refractory period to name a few. Thus, unity or even duality of viewpoint on the nature of attention does not appear to be easily achieved.

However, if one were to search for a single basic attentional processes from everyday experience, it would probably be focusing or concentrating. These words and their noun counterparts are found frequently in the everyday language of attention, when we experience difficulty focusing in a noisy or confusing environment or during internal turmoil or distraction. Anyone from children to their teachers, sports figures and commentators to professors and presidents refer to or complain about the effort involved in concentrating or difficulty in focusing attention. Concentration is the first of six meanings of attention in Moray's review (1969) and tends to be the first mentioned in more recent reviews.

However, if concentration were embraced as the sole meaning of attention, our everyday experience of shifting or switching attention from one source to another would be ignored. Shifting attention is apparent in the exploration of our surrounding environment as we move our eyes to a new point of fixation or shift to interesting sounds or smells, etc. These two processes were central to the accounts of attention developed by the two founders of scientific psychology, Wilhelm Wundt and William James. Further, they were directly mirrored in James' famous metaphor of the alternating perchings (focusing) and flights (shifting) of a bird. These two processes not only seem pervasive in everyday experience, but also appear to have considerable phenomenal validity, suggesting that they are a part of mental activity immediately available for our metacognitive analysis. Finally, focusing and switching are both referred to as basic attentional processes in recent reviews of the literature (Allport. 1990; Kinchla, 1992).

A third meaning of attention, selection or filtering, was mentioned by James (1890) as part of the very definition of the stream of consciousness. Selective attention is indicated by the extensive research on dichotic listening and visual search, in which stimuli are rapidly scanned, as in shadowing the stream of words in a target ear, or searching for a target letter among a series of distractors. This meaning appears more complex than simply shifting the focus of attention, but it might include shifting along with filtering the irrelevant background information as the target item or stream is selected.

Finally, concentration is often extended over a prolonged period of time, although probably not continuously. The common terms for this are vigilance or watch keeping, but it is sometimes ambiguously called sustained attention, since some authors (e.g. Stankov, 1988) use this expression as an alternative to simple concentration. Vigilance has its own extensive body of supportive research (see Parasuraman and Davies, 1982) with substantial evidence of individual differences.

The four meanings just described correspond to the first four mentioned by Moray (1969) in his review of previous research. Given that there are research paradigms which appear to represent these meanings, we might expect to find these factors in an appropriately designed

battery of attention related tasks based upon the experimental literature. Thus, we expected to find evidence for concentration, shifting, selective attention, and vigilance.

Introduction to the Factor Analytic Studies

In the subsequent search for relevant research sixteen factor analytic studies were found, most in a spurt published in the last decade (see Table 2). Two were older, an early study by Whittenborn (1943) referenced by Moray (1969) and another by Sack and Rice (1974). Thus, it appears that there has been an interest in isolating factors of attention for more than 50 years, but that the older literature is largely unknown in the current era. Further, groups of researchers have independently explored batteries of tasks in recent years using many of the same tasks, but with limited cross references between groups in the articles and chapters reviewed below. The majority of these researchers were clinical neuropsychologists, some of whom have investigated factors of attention, and others who have tried to isolate and define so called executive functions (EF) related to the prefrontal cortex. As mentioned above there is substantial overlap in the respective test batteries of these two groups.

From a number of recent sources (e.g. Krasnagor and Lyons, 1994) executive functions include planning, the sequencing of actions, the ability to flexibly change set, and inhibit irrelevant information and prepotent responses. Although executive functions are typically associated with frontal lobe functioning and related deficits in the neuropsychological literature, they should also have an apparent relationship to the central executive of the working memory system developed by Baddeley and his coworkers (Baddeley, 1986; Baddeley, 1996). Pennington (1994) has recently made this connection in his theoretical treatment of the subject. Executive functions, in contrast to our projected four attention factors, appear to involve a more complex level of cognitive processing. Thus, an important theoretical question appears to be where attention ends and executive functions begin. Alternatively stated, should attention be included as a set of executive functions?

Clearly the sort of task which is purported to tap executive function, such as the Wisconsin Card Sort test (WCS), would require focusing attention on each stimulus prior to making the required conceptual judgment, but focusing should be just the initial component process followed by others. As a test of the ability to flexibly shift set, the WCS was used in some of the studies cited below as an executive function test. However, in another group of studies set shifting was identified with shifting of attention (e.g. Mirsky, 1987), which seems to be mixing levels of cognitive processes. Since set shifting involves changing hypotheses about the correct problem solution, it must include a group of processes beyond simply shifting attention.

Most tasks such as the WCS require more than just one cognitive process to achieve a response. Thus, in a task analysis a particular test may be seen as made up of a set of components or stages, some of which can be accomplished concurrently, while others occur in succession. The result is that tests typically may rest upon more than one ability. A good

example is found in the trail making tests (Trails A and B) found in many of the studies reviewed below, in which a random array of numbers must be connected in ascending order with lines (Trials A), or alternating letters and numbers connected (Trails B). Rapid scanning of the array is necessary to find the target, which is defined by remembering where in the ascending sequence one is, as well as alternating sets of symbols in Trails B (A-1, B-2, etc.), possibly a simple case of shifting set. Finally, the last component is fine perceptual/motor control required to draw the trail. Depending upon the environment of other tests in a battery from which the factors are extracted, one component may predominate over others in determining the factor loading of that test, if it is the major source of covariance with the other tests. Thus, in a particular battery a test may be pulled in one direction, while it may acquire a different set of factor companions in another, or it may wind up with multiple loadings. Such variation in component dominance may account for some of the discrepancies among the studies reviewed below.

Review of Factor Analytic Studies

The studies found in Table 2 can be categorized according to whether the primary theme expressed in the title was attention on the one hand or prefrontal lobe or executive function on the other. There are twelve in the attention group and five in the executive group, although as will become apparent this is a broadly intersecting classification. A brief overview of the studies will now be presented in terms of the tests used and the factors found.

In the first factor analytic study of attention Wittenborn (1943) had as his major interest the separation of attention as a factor from other primary mental abilities and general intelligence. His data were reanalyzed by Stankov (1983) with improved methods. In both analyses a factor called concentration by Wittenborn was based upon tasks which required persons to retain multiple instructions, and use the one appropriate to the current stimulus, as exemplified in the number pairs task. In this task a + was the response when the first number was larger than the second, a minus when the first was smaller and the second was odd, and a 0 when they were the same or the second was larger and even. This task and other ones he designed with a similar need for holding multiple instructions, all require the selection of the correct instruction and suppression of the ones irrelevant to the present stimulus. Since these tasks require multiple concurrent processes with one active and relevant at the moment, they involve considerably more than just focusing attention implied by the factor name and better fit current views about executive function tasks. Thus, in Wittenborn's pioneering attempt to factorially separate attention from other abilities, he inadvertently introduced a confusion between higher order executive function and simple focusing of attention. This confusion continues to be a major problem in the current literature quite independently of Wittenborn's work, which is only selectively acknowledged in more recent literature (e.g., Moray, 1969; Stankov, 1983, 1988).

Although Wittenborn didn't consider a second perceptual factor as attention related, it emerged from several search tasks, such as a digit canceling task, which involved rapid scanning of stimuli for targets and is the hallmark of visual selective attention (see Stankov, 1983). This

latter factor has had a prominent history in the abilities literature, beginning with the early exploration of it by Thurstone (1938, p.81).

The second study by Sack and Rice (1974) resulted in three factors from oblique rotation, with three of their ten tests loading substantially on two factors . Their first factor was related to Witkin's work on embedded figures (Witkin, Dyk, Faterson, Goodenough, and Karp, 1962) with three embedded figures tests loading on the factor. Following one of Witkin's co-workers, Karp (1963), this factor was named selectivity. Their second factor, resistance to distraction which they associated with the ability to sustain concentration, was based upon three search tasks with distractors including a cancellation task taken from a battery also developed by Karp (1962). He had previously found (Karp, 1963) that embedded figures and his search/distractibility tasks loaded on separate factors. The final factor, called shift, was represented by an anagrams task which required set shifting and the Stroop task, which also had a smaller loading on the concentration factor.

Stankov (1988) was unique among this group in that he was interested in the relation between factors of attention and fluid intelligence (Gf). He used a large battery of 36 tests including 11 potential measures of attention, as well as both measures of crystal and fluid G, and other tasks testing various perceptual and cognitive processes including divided attention. Some of the latter were measures of working memory as currently conceived. His concentration factor was based upon two of Wittenborn's tasks, number pairs (described above) and letter lists. A cued instruction switching task, also requiring target switching similar to the other two tasks also loaded on this factor. His attentional flexibility factor was based upon Luchin's water jars and anagrams, both of which are tests of set shifting, but the factor also included a modest loading on an embedded figures test. Finally, his search or perceptual speed factor came from search tasks somewhat like the first two studies, but it also included total Stroop time and the WAIS Digit Symbol Substitution test (DSS), which is found in a number of other studies. This factor structure was essentially replicated by Stankov, Roberts and Spilsbury (1994) with a similar but smaller battery and a smaller sample. Curiously the anagrams task migrated to the search factor without any appreciable secondary loading on the concentration factor, and the instruction switching task moved to load with Luchin's Jars. They attributed these changes to modifications in the tasks including a reduction in the number of trials.

A second set of five "attention" studies form a group with a common core of tasks beginning with an initial study by Mirsky (1987). The first study was followed by an extensive set of replications by his research group on both an adult sample consisting of a mixed group of patients and normals and a child sample (MIrsky, Anthony, Duncan, Ahearn, and Kellam, 1991), as well as three published replications by others. There was also an elaborate theoretical treatment with corresponding localization of function for the factors in both cortical and subcortical loci (Mirsky, et al., 1991). The first of Mirsky's factors was referred to as focus/execute, which was defined by the DDS, Talland's letter cancellation task, Trails A & B, and the Stroop task. Although Mirsky's theoretical elaboration for this factor is compelling, the tasks loading on this factor are quite similar and mostly overlap with Stankov's search factor as

well as search tasks in the two early studies and others to be decribed below.

The second factor was apparently a set shifting factor based upon three dependent variables from the WCS loading on this factor. Mirsky called this factor "shift," with the implication that this is an attention shifting factor, although as previously mentioned a more complex executive set shifting is involved in the problem solving nature of this task, which will be further discussed below.

The third factor was solely based upon the AX form of the continuous performance task (CPT), which Mirsky had previously helped to develop (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). In the CPT the subject responds to a long series of stimuli (e.g. letters or digits) for perhaps 10 or more minutes in a go no-go format with relatively rare targets (25%). In the AX form there is a conditional procedure in which a response is only made to an X following an A. Among the group of studies reviewed this is the only speeded reaction time (RT) task, although there are others where time measures acquired (e.g. Trails and WCS RT). Mirsky labeled this as a sustain factor, which in the history of the CPT has been identified with vigilance or the prolonged deployment of attention over a relatively long time period. However, as mentioned above the term sustain was also used by others to merely refer to concentration or focused attention. On the contrary, the vigilance meaning of sustained attention has classically been related to watch keeping in which long term vigilance decrements were the primary object of study. The last factor found, named Encode, was based upon digit span and arithmetic ability and does not appear to be an attentional factor. Mirsky and his colleagues have continued to use this battery to test other groups.

There were four additional studies which were patterned at least in part after Mirsky's test battery. The first was an unpublished study by K.S.Kendler mentioned by Mirsky et al. (1991) as a personal communication, in which 10 out of 12 "attention" variables were classified in the same way as Mirsky's factors. The second study by Steinhauer, Zubin, Condray, Shaw, Peters and van Kammen (1991) included a brief sketch of Mirsky's four factors. They used Trails B, WSC and CPT from Mirsky's battery, but also used other tests and electrophysiological measures, suggesting that they discovered Mirsky's research after they had begun theirs. Their first factor consisted of a relational concepts scale (Luria-Nebraska), WAIS-R Block Design, Trails B, and, contrary to Mirsky's studies, WCS perseverative and nonperseverative errors. Factor 2 and 3 were made up of P300 amplitude and latency respectively. These measures were obtained during relatively rare target tones in a counting and a choice RT task. The fourth factor included two variables from the CPT and a span of apprehension test.

The third study by Kremen, Seidman, Faraone, Pepple, and Tsuang (1992) was a close replication of the Mirsky battery on a sample of schizophrenics, omitting the cancellation and Stroop tasks and using an auditory form of the CPT. They essentially found the same factor structure as Mirsky, however they renamed the factors as follows. The first was perceptual motor speed, which is closer to the operations involved in the DDS and Trails and reflects the search/scan operations in these tasks better than Focus/Execute. The WCS factor was called

flexibility like the set shifting factors found by Sack and Rice (1974) and Stankov (1988). The other two factors were more problematically renamed vigilance for sustain and mental control for encode.

The fourth study by Pogge, Stokes, and Harvey (1994) was also a replication of the Mirsky studies with a large sample of adolescents. Using confirmatory factor analysis they tested both a four factor model based upon Mirsky's set, and a three factor model in which they merged the WCS with DDS and Trails. They found that there was only a small nonsignificant improvement in fit with the four factor model. This outcome suggests that the combination of tests (WCS, DDS, and Trails) could be interpreted as a general executive function factor. However, there are other reasons detailed below to segregate set shifting represented by WCS and Luchin's tests (Stankov, 1988).

A second smaller group of neuropsychological studies of attention tests was begun by Shum, McFarland, and Bain (1990) with a more pragmatic orientation, but their battery of tests substantially overlapped with those used by Mirsky. They did not include the WCS or CPT. They arrived at a three factor solution, the first of which looked much like Mirsky's focus/execute. It consisted of DDS, letter cancellation, Trails A and B, and several variants of the DDS and was interpreted as visuo-motor scanning ability. Unlike Mirsky's and Stankov's studies the Stroop task loaded on the second factor, although not as strongly as two serial subtraction tasks in which a seed number was given from which backward counting began either by 7 or 13. This factor was interpreted as involving selective extracting and processing of information and is quite different from others found in this review. The third factor was made up of digit span and the Knox Cube test. This factor is much like Mirsky's encode factor, although the authors refer to it as "visual and auditory spanning."

After finding these factors in a group of normal subjects, Shum, et al. (1990) replicated their study, testing the fit of this factor structure in a mixed group of patients. Picano, Klusman, Hornbostel, and Moulton (1992) found the same three factors using a subset of the Shum et al. (1990) battery. In their study the Stroop task loaded more strongly on the extraction/processing factor than the reverse serial subtraction tasks. Finally Schmidt, Trueblood, Merwin, and Durham (1994) in a factor analysis of a large comprehensive group of tests, the Halstead-Reitan Battery, the WAIS-R, and the Wechsler Memory Scale, found evidence for the first and third factors, visuomotor scanning and visual/auditory span.

The last five studies were explorations of executive function, although they had a number of tests in common with the preceding. The major interest in the first three studies was the development of prefrontal lobe function in children and young adults from a neuropsychological point of view (Shute and Huertas, 1990; Levin, Culhane, Hartmann, Evankovich, Mattson, Harwood, Ringholz, Ewing-Cobbs, and Fletcher ,1990; and Welsh, Pennington, and Grossier, 1991).

Four factors were found in the study by Shute and Huertas (1990), the first two of which

line up somewhat with previous studies. It should be noted that, although their theoretical treatment was developmental within a Piagetian framework, their subjects were college undergraduates. The first was a complex factor made up of a category test, the Piagetian Shadows Test (Shute, Howard and Steyaert, 1984), which is a developmental test of spatial reasoning, Trails B, and WCS perseverative errors. With such a mix this group appears to constitute a more global executive function factor than was found when the WCS was used by itself or in combination with a single related test seen in several studies below (see Mirsky et al., 1991 p. 125 for discussion). The second factor was comprised of the DSS and Trails A with a substantial secondary loading from Trails B, suggesting a search factor as found in most of the preceding studies. The third and fourth factors were unique to this study and were based upon a time estimation task and an internal scanning/judgement task in which lines of "Jingle Bells" were scanned from memory in order to detect particular target letters. These were presented both in single and dual task format with each other, and each comprised a factor across format. However, it should be noted that the internal scanning test could have loaded on factor two with the other measures of selective scanning. Since it did not, the internal scan may be a separate factor as the authors suggest.

Levin, et al., (1991) obtained three factors, the first of which was based upon three verbal tasks, the California Verbal Learning Test, Word Fluency, and Twenty Questions, which they called semantic association and concept formation. Their second factor, freedom from perseveration, was based upon false alarms on a go/no-go task, and perseverative errors (PE) from the WCS. This result lends some additional generality to the factor based solely upon the WCS in the Mirsky studies and replications. The third factor was mainly defined by the Tower of London test (Shallice, 1982), which is a simplified version of the Tower of Hanoi test. There were also substantial secondary loadings for word fluency and twenty questions, which has a definite planning component.

Welch et al., (1991) found three factors with their battery, The first factor contained a heterogeneous collection of tests like Shute and Huertas (1991) including verbal fluency, a visual search task for targets among distractors, a motor sequencing task consisting of rapidly touching the fingers to the thumb in order, and a picture recognition task in which pictures previously seen were targets. Rapid scanning of either external stimuli or memory may be the primary operations tapped by this factor. The second factor was based upon WCS-PE and a complex picture recognition test, the MFFT, also providing additional extension of the WCS factor as found in Levin, et al. (1991). Their third factor was made up of three and four disk versions of the Tower of Hanoi test.

Daignenault, Braün, and Whitaker (1992) were involved with testing two different factor models using confirmatory factor analysis. The first was based upon neuropsychological practice and related categories of functions. The second was based upon an extension of work with prefrontal lesions in monkeys (Goldman-Rakic, 1987). The four factors in the latter model were based upon the stimulus modality (verbal/spatial) crossed with the response modality (verbal/manual). Although only the second of their models obtained a satisfactory fit, there were a number of discrepancies from the way in which tasks were expected to fit the model, which

were hard to reconcile. Examination of their correlation matrix reveals that there were substantial correlations (.42 to .62) between the Self Ordered Pointing Task (SOPT) and error scores on the Porteus Maze Test and WCS. In the SOPT a series of cards are presented in a deck with the same twelve stimuli (words or forms in different decks), and the correct response is to point at a different stimulus on each card, remembering and suppressing responses to the stimuli previously pointed at. The relatively high intercorrelations among these tests suggests another possible extension of executive function tests related to the WCS. However, in their CFA model these three tests were all hypothesized to represent different factors. The Stroop Test and Trails B used in many of the batteries reviewed here had relatively small correlations with other tests. Since most other studies surveyed found some convergence on latent factors with exploratory factor analysis, the authors probably should have proceeded in a similar way to discover the natural factor structure in their data, in addition to testing models.

Finally, the most recent exploration of executive function has been carried out by Pennington (1997) in a large sample of children including around 40% with diagnosed reading disorder. The first of the two executive factors he obtained was based upon two tests which tap inhibition of responding, the CPT-AX, and the stop signal task (Logan, 1994) in which a series of responses, usually in a choice reaction time format, are halted with the "stop" stimulus. Inhibition had been implicated as part of executive functioning by Logan (1994) and Dempster and Brainerd (1995) among others. The second factor was based upon the WCS and the Contingency Naming Test (CNT), which is also a set shifting task. It should be noted that perseverative errors on the WCS, which is frequently conceived in terms of failure of inhibition (find evidence) was not significantly loaded on the inhibition factor.

A subset of the large sample was given a more extensive battery including the four tests from the previous analysis. The first factor was based on two complex span measures (sentence and counting) as well as digit span, representing working memory as a third possible executive function. The second factor, although labeled set shifting because of the WSC and CNT, included two measures of IQ, Ravens's Matrices and WAIS, as well as a modest loading for the Stroop test. The third factor was made up of Trails (B - A) and a composite reading score from the Peabody Individual Achievement Test. The fourth was the inhibition factor found in the first analysis. Pennington (1997) points out that the inhibition factor is independent of intelligence, while the set shifting factor, which he also labels "cognitive flexibility," is associated with Raven's matrices, the classic measure of fluid intelligence. He could have made the same point for his working memory factor as well.

Summary of the factors

There are sufficient commonalities in the use of tests and factor loadings across the studies reviewed to suggest several thematic factors, although as previously mentioned different authors use the same term (e.g. concentration, perceptual speed) for factors arising from quite different tests. There is clear evidence for the third of the four proposed attention factors, search or selective attention. Search, which is frequently called perceptual/clerical speed (Stankov,

1988), involves rapid scanning of arrays to find targets, same/different matching between arrays, or possibly scanning internal representations from memory. Selective scanning is represented by assorted visual search tasks beginning with the early studies (Wittenborn 1943; Sack and Rice, 1974), in which cancellation tasks are part of the common core. Besides cancellation and other simple visual search tasks, the common marker tasks have been the Trails tasks and the DSS. One or both of these were found in ten of the studies reviewed. Where cancellation, DSS, and Trails occurred together, they loaded on the same factor (Mirsky, 1987; Mirsky et al 1991; Shum et al., 1990). The DSS and one or both of the Trails tests loaded on the same factor in five additional studies, the replications of Mirsky et al. (1991) by Kremen et al.(1992) and Pogge et al., 1994, and the replications of Shum et al., 1990 (Picano, 1992; Schmidt et al., 1994), as well as Shute and Huertas (1990). Finally, The DSS loaded with visual search tasks in both of Stankov's studies (Stankov, 1988; Stankov, et al.(1994), and Trails A and B Loaded with a composite reading score which could be related to selective scanning in Pennington (1997). Thus, there is substantial evidence for selective scanning in fourteen of the studies reviewed in which one or more markers were included. However, there is the limitation that all the tasks were visual, so that future work should broaden the modality representation with auditory or tactile selective attention tasks.

Less extensive evidence was found for vigilance, the fourth of the projected factors. Mirsky (1987) and Mirsky et al. (1991) and the replications by Kremen et al.(1992) and Pogge, et al. (1994) each found a CPT factor derived from two to four dependent variables including reaction time and accuracy, but without a second independent test of vigilance. There was some generality added by Kremen et al.(1992) in that they used an auditorily presented CPT. Steinhauer, et al. (1991) obtained a factor defined by the CPT and the Span of Apprehension test in which a target digit is searched for among nine distractors on each trial. However the latter task is alleged to be a test of resistance to distractibility (Mirsky et al., 1991). Further, it is like some visual search tasks (e.g., Thurstone, 1938; Stankov, 1988), so that it is not clear what the latent variable might be, resistance to distractibility or sustained attention in the vigilance sense. To further complicate matters Pennington (1997) found that the CPT loaded with the stop signal task (Logan, 1994) on a factor interpreted as inhibition. So, perhaps this is a case where the task environment in which the CPT is placed determines the task component responsible for how it loads with other tasks.

Thus, it is not yet clear that the CPT represents a marker for a vigilance factor, in spite of a fairly widespread view that it does. Ballard (1996) in reviewing vigilance research notes that CPTs produce vigilance decrements, although they are typically shallower than other vigilance tasks partly because of the short duration of the task compared to classic vigilence tasks. Further, she points out that vigilance decrements are seldom used as variables in studies of sustained attention.

Evidence for an attention shifting factor is unclear and hinges on the the interpretation of the WCS, which is the most commonly occurring single test other than the DSS, appearing in ten of the studies reviewed. The question remains, as we raised it before examining the existing

literature, whether the WCS represents a test of the simple shifting of attention as is maintained by Mirsky, 1987 and Mirsky et al. (1991); or does it entail a more complex level of executive function, namely, conceptual flexibility, shifting sets or hypothesis testing. Mirsky et al. (1991, p 130) acknowledged this problem, noting that the boundary between attention and executive function is fuzzy. In the Mirsky studies and the replication by Kremen et al.(1992) the WCS emerged as a factor by itself with a cluster of a few dependent variables from the task, suggesting the possibility of a task specific factor.

In several studies there was a second task loading with the WCS variables. First, Mirsky et al. (1991) briefly described a small substudy in which the Reciprocal Motor Programs test loaded with the WCS (number of categories attained). This task, as a test of flexibility, requires a response opposite the one given by the examiner, e.g. tapping twice when the examiner taps once. Inhibition of the response mirroring the examiner could be the underlying component of the test reflected in this factor. Likewise inhibition of the previously correct basis for responding (hypothesis) should be reflected in the commonly used WCS variables, suggesting inhibition as the latent variable involved in this factor. A second study by Levin, et al, (1991) independently corroborates this interpretation with a go/no-go task in which false alarms and WCS perseverative errors comprised a factor. False alarms are most directly interpreted as a failure to inhibit incorrect responses. Finally Welch et al. (1991) included the MFFT, which requires fine complex form discrimination, selecting a match to the target from six alternatives, and is characterized as a test of impulse control, hypothesis testing, and visual search. MFFT RT and errors both loaded with WCS-PE, also implicating inhibition as the latent variable.

However the picture just presented is not so clear in five additional studies in which WSC loaded with a variety of other executive function tests, suggesting that inhibition of responding may not be the only component process tapped, or that other tasks, such as DDS or Trails B may in the right test environment load on some other factor than selective scanning, such as set shifting or inhibition. In the studies by Shute and Huertas (1990) and Steinhauer, et al. (1991) the WCS was associated with a diverse group of executive function tasks. Both included Trails B and several measures which might reflect Gf or inhibition or both, if inhibition were an essential part of Gf, as Dempster (1991) maintains. In the study by Daignenault, et al.(1992) the substantial correlations (.42 to .62) between the SOPT and error scores on the Porteus Maze Test and WCS further suggest the relation between the WCS and inhibition (SOPT) and G (Porteus Maze Test).

A further complication is found in the study by Pogge et al.(1994) in which they discovered that a CFA with four factors, separating WCS-PE as a factor, did not significantly improve their fit to the data with three factors in which WCS-PE loaded with DDS and Trails B, suggesting that the set shifting component of Trails B and some aspect of the DDS, yet to be identified, shared the same latent variable. This latter interpretation gains some support from the Shute and Huertas (1990) study already mentioned in this summary. In their first factor Trails B loaded with WCS-PE, although the two possible G measures were the dominant tests on the factor. Trails B also had a marked secondary loading on an apparent search factor defined by

DDS and Trails A, providing evidence that hypothetical multiple components in a task, shifting sets and selective scanning may result in separate pools of covariance.

The most recent study of executive function, Pennington (1997), provides the final complication in interpreting the latent variable(s) tapped by the WCS. On the positive side the WCS loaded with the CNT, another set shifting task, as well as two measures of intelligence, Ravens Matrices and the WAIS, somewhat along the line of the studies by Shute and Huertas (1990) and Steinhauer, et al. (1991). On the negative side The WCS had a negligible loading on the inhibition factor defined by the CPT-AX and the stop signal task, contrary to the findings of Mirsky et al. (1991), Levin et al.(1991), and Welch et al. (1991) discussed above.

Clearly further investigation of the WCS is needed to clarify the somewhat confusing collection of previous outcomes, although there are the some thematic regularities. Part of the problem of course is the need to make comparisons across studies with both explicit similarities and differences in batteries and samples, as well as unknown discrepancies. On the other hand the nature of the WCS may be the problem in that the putative set shifting nature of the task may be too complex or amorphous to be used in factor analytic studies of executive function, in spite of its popularity as diagnostic tool.

If there is a basic set shifting function, then there ought to be other potential tests of set shifting to combine in a battery with the WCS, as the CNT was in Pennington's (1997) study. Several other studies also contain set shifting tests, which could be used to this end. The best candidate is the Luchin's Jar task found in both Stankov (1988) and Stankov, et al.(1994). Unfortunately the companion tests loading on an apparent flexibility factor changed between the two studies from anagrams, also found in the Sack & Rice (1974) study, to an instruction shifting task, which could also reasonably represent cognitive flexibility. Either of these tasks could be incorporated in a battery with the WCS, along with other possible candidates, including new tasks designed to be explicit markers for set shifting or other probable components ofthe WCS.

Last, there is ample evidence in this literature for a working memory factor, which is not primarily related to attention, since it is based upon various forms of memory span. Rather, working memory is part of the current discussion of executive function (see Pennington, 1997), as well as a part of the literature on human abilites (see Stankov, 1983, 1988) in the form of short term acquisition and retrieval (SAR). In the Mirsky studies (Mirsky, 1987; Mirsky et al 1991) the factor, which they labeled "encode," was based upon the ubiquitous digit span and an arithmetic task, as it was in the replications by Kremen et al.(1992) and Pogge et al.(1994). In both the Stankov (1988) and Stankov, et al.(1994) studies an SAR factor was obtained based upon digit span and Crowders span, in which correct ordered recall of nine digit lists was scored. Generality was provided by Shum et al. (1990) in their auditory/visual spanning factor based upon digit span and Knox cubes, a visual nonverbal short term memory task. The most thorough study of the working memory factor among this group was found in Pennington's (1997) factor analysis of executive function, in which he used two more complex measures of working memory span, sentence and counting span, along with forward digit span, all of which

loaded on a factor separate from the other two executive factors, set shifting and inhibition. Thus, eight studies and several other replications provide supportive evidence for this factor, which is the only fairly well defined executive function so far identified. Other executive factors will require more extensive and elaborate investigation, although Pennington (1997) has provided a good beginning.

Given the preceding review, what is the status of evidence for the originally proposed group of four factors of attention? First, there is no evidence for the primary focusing or concentration factor, which has been mistaken either for a higher level of executive function (e.g. Stankov, 1988) or selective scanning or search (e.g. Mirsky, 1987), so that an approximation to pure focusing yet remains to be found. This factor might emerge from reaction time tasks requiring concentration on stimuli presented in the center of a computer screen without any need to shift attention.

Second, there is also no evidence for simple attention shifting in the complicated picture of executive function surrounding the WCS. Rather than set shifting some sort of simple tasks in which attention is switched from one source to another, such as is found in cuing experiments (see Posner & Raichle, 1994), might be able to capture this basic process.

Third, there is extensive evidence for attentional selectivity, which from its basis in dichotic listening and visual search tasks, make it appear separate from simple attention switching. This evidence appears in selective scanning/perceptual speed factors found in most of the studies reviewed.

Fourth, there is only weak evidence for vigilance or sustained attention in the studies which included the CPT. The evidence is not clear because of the mixture of other tasks which loaded with the CPT (Pennington, 1997; Steinhauer, et al., 1991), and the lack of other markers for vigilance. Thus, support for a vigilance dimension awaits a battery containing more relevant tasks.

Development of the ASAP battery

There appear to be several factors that gain support only from the experimental literature on attention (concentration and attention shifting). On the other hand, two others (search and vigilence) find support in both the experimental and factor analytic literature. We designed a new battery of tasks in an attempt to determine the latent factors of attention reflecting both of these groups. In addition we included tasks which we hoped would clarify some aspects of the relation between attention and executive function not found in the factor analytic literature. Two primary experiments were conducted.

Experiment 1

Participants. Air Force recruits were tested at Lackland AFB in the first experiment. A

total of 192 participants were tested, although problems with the software resulted in incomplete tests for 43 volunteers.

Apparatus. The Alpha version of the Assessment Software for Attention Profiles (ASAP-A) was used in this study. The tasks were programmed in Microsoft QuickBasic 4.5 and compiled. Each task was administered on IBM-compatible, 80386-based computers in DOS mode.

The battery began with simple and choice reaction time tasks, which were not used in any of the studies reviewed. There were several tasks which were unique to this study relative to other investigations of the factors of attention. The Search tasks were each based upon three set sizes (10, 40, 70) in order to provide slope and intercept estimates, and three conditions were administered (Search 1: F embedded in E, L, & T; Search 2: F embedded in O, C, Q; Search 3: F embedded in E, L, T, O). The Cue task (based on the cost/benefit tasks used successfully by Posner and many others) provided central or peripheral arrows indicating where a target would occur. In the Anti task (based on the Anti-saccade task described by Hallett and colleagues (Hallett, 1978; Hallett & Adams, 1980), the target occurred on the side opposite the direction in which both central and peripheral arrows were pointed. Thus, the participant had to look in the opposite direction from the cue. The Comparison task required a same/different judgement of two letters spaced within a single focus, or separated to require saccadic movement from one to the other. Finally, a pursuit tracking task was presented both singly and in a dual task format with a serial probe letter recognition task. This task was adapted from one used frequently in our laboratory, and also used in the "Tester's Workbench" battery of cognitive tasks produced by the Army.

Because of the possible overlap between attention and executive functions, some of the tasks from the previous factor analytic studies were included in our group of laboratory based tasks and other tests. The CPT, Stroop, Trails-B, and Cancel that we developed are similar to those found in studies described above. Our Sort task was a two-dimensional set shifting task similar to the WCS, but using hierarchically organized stimuli (e.g., a big F made up of smaller Fs or Es). The battery was rounded out with three standardized self report tests, which were possibly related to attention: the Cognitive Failures Questionnaire (CFQ), a survey of various kinds of absent mindedness (Broadbent, Cooper, FitzGerald, & Parkes); the Boredom Proneness Scale (BPS) (Farmer & Sundberg, 1986); and the NASA Task Load Index (TLX), a self-report measure of cognitive workload (Hart & Staveland, 1988).

The list of tasks that were used in this experiment appears in Appendix A. The ASAP-A battery constituted those tasks that had been tested in pilot studies and found to produce reliable measures in a practical period of time. It bears emphasizing that each of these tasks were nominated from the laboratory or individual-differences literatures on attention or from our own earlier research on attention conducted at the Center of Excellence for Research on Training.

Procedure. Each participant was seated at an individual computer station within a large

room of computers. The recruits responded to computer-generated stimuli using a mouse, moving the cursor or clicking according to instructions that were provided for each task. The battery of tasks were arranged in a fixed sequence and administered in a batch file. The participants controlled the pace of task administration (i.e., they could rest between tests), but trials within a task were typically computer-paced. The entire battery of tasks required betweem 1 and 2 hours to complete.

Results. Data from the ASAP-A were summarized and filtered for outliers. Individual means for 85 variables were computed and analyzed using principal components analysis for the 149 remaining participants in this experiment.

Results from this initial factor analysis and from inter-task and inter-measure correlations were used principally to modify the task battery for Experiment 2. No detailed consideration of these results will be considered here. However, some of the results were sufficiently worrisome to cause us to re-design the SORT task and to make significant changes to TRACK, CANCEL, and COMP (aka RSVP in tables) tasks. Because the measures showed poor correlation and distribution characteristics or failed to load on salient factors in the principal components analysis, we dropped the EST, INHIB, SELTR, and MROT, RNJ, and SWITCH tasks from Experiment 2.

The ASAP-A data from these 149 recruits are currently being re-analyzed (following the procedures discussed below) to determine the degree of correspondence between Experiments 1 and 2.

Experiment 2

The primary result from Experiment 1 was a revised battery of tasks, ASAP-Beta (ASAP-B). This reflected the elimination of some tasks that seemed not to contribute to our assessment of attention skills, the repair or reprogramming of tasks that functioned poorly, and the elimination of conditions or entire tasks in an attempt to reduce the amount of time required for testing.

Participants. Again, Air Force recruits at Lackland AFB were made available for this experiment. A total of 525 recruits, including 92 women, completed the ASAP-B battery. The participants ranged in age from 17 to 35 years (mean age = 20.12). Two-thirds of the sample identified themselves as white/Caucasian, whereas 19% identified themselves as black/African-American and the remaining participants were identified as belonging to other racial or ethnic groups.

Apparatus. The hardware used in Experiment 2 was identical to that in Experiment 1. The battery of tasks used in this study, together with the measures each yields, are shown in Table 3.

Procedure. As in Experiment 1, participants were tested in groups, with each recruit seated at a computer station and proceeding through the battery at his or her own pace. The ASAP battery took about 2 hours to complete in a single session.

In addition to the ASAP tasks, each participant completed one of three criterion tasks. These tasks (described below) were administered before the ASAP battery was initiated.

Results. The 16 tasks of ASAP-B yield 55 basic dependent measures (response time, accuracy, number of responses or errors, self-report survey score, and so forth). Outlier scores were screened from each measure by removing outliers 3 standard deviations on either side of the mean, and means were re-computed for each participant, task, measure, and condition.

Principal components analysis with varimax rotation was performed on the data set with at least one and usually more variables representing each of the 16 tasks, because most of the tasks had both RT and percent-correct measures as well as other variables (e.g., Search false alarms, Sort perseverative errors, tracking error). In preliminary factor analyses, RT and accuracy measures loaded on separate factors with a large factor of each followed by one or more smaller separate factors of the two kinds of variables, depending upon the number of factors set for the run. Many of these factors were represented by one or two variables making them difficult to interpret as reflecting other than task- or method-variance.

A more easily interpreted set of analyses was obtained from separate principal components analyses of the different types of variables (see Tables 4 and 5). The first group of measures consisted of the of various psychomotor performance tasks including RT variables from speeded reaction tasks with, tracking error, number of correct cancels, and Trails B completion time. The second group of measures consisted of accuracy and psychometric measures. It should be noted that variables from the two groups of measures did not load on common factors in any of the preliminary analyses, and that the correlations between RT and accuracy variables from the same task tended to be low (see Stankov, et al., 1994 for similar results).

PSYCHOMOTOR VARIABLES: In the principal components analysis of psychomotor variables there were five factors with eigenvalues greater than one. The first factor consisted of RTs from the three Stroop conditions, choice and simple reaction tasks, CPT, and the same different comparison task loading in that order. This grouping is on the surface a cognitive speed factor, but we take the position that this is the latent variable reflecting the focusing operation missing from previous studies. This assertion is based upon the fact that the tasks with highest loadings demand concentration on stimuli in the center of the screen without requiring shifting of attention or other more complex processes. These include the variations of the Stroop task, the choice and simple reaction tasks, and the CPT.

The second factor is made up of the four Anti and Cue RTs, which have as their common basis a cue that indicates the direction in which attention is to be shifted, suggesting that these

variables represent the attention shifting factor also not found in previous studies. The peripheral Anti condition, in which attention has to be shifted away from the arrow cue, is the dominant variable followed by the central Anti condition and the peripheral and central Cue conditions. The central and peripheral Cue conditions also have substantial secondary loading on the first factor.

The third factor is the search factor frequently found in the literature reviewed, which has two Search task RTs as the defining variables and Cancel and Trails-B, reflecting the results of the previous research. The fourth factor is singularly based upon the single and dual tracking error with a secondary loading from the cancellation task, which is suggestive of a psychomotor skill factor. The fifth factor is made up of single and dual memory RT and, like the fourth, may represent a task specific factor.

ACCURACY VARIABLES: Analysis of the accuracy (percent correct) and similar dependent measures, including the three questionnaires, also yielded five factors according to the eigenvalue criterion. The first is comprised of a variety of tasks beginning with choice RT accuracy, along with five Anti and Cue accuracy measures, and Comparison accuracy. Given the range of these tasks, this appears to be a general accuracy variable, which is suggestive of carefulness in making correct responses. The second factor is comprised of three Sort variables (number of reversals, percent correct, and number of perseverative errors), reflecting the frequently found set-shifting factor from previous studies. The third factor is a specific memory accuracy factor from the probe recognition task like the memory RT factor found in the first analysis. The fourth factor is made up of the three self report tests (BPS and TLX, CFQ) which are all based upon reflective responses about a variety of psychological processes. Therefore, this could be a metacognition factor. The fifth factor is comprised of two measures of search accuracy. This result suggests a search accuracy or target detection factor which is separate from time-based selective scanning, since these variables also sort out on separate factors in preliminary analyses in which all variables were combined.

Discussion

It appears that we have evidence supporting three of the four projected factors. The first psychomotor/RT factor, although superficially a general speed factor, appears to be the *Focus* factor missing from previous studies. The focusing nature of this factor is particularly evident in the conditions of the Stroop task in which red or blue print in the center of the screen was responded to in a choice RT format with compatible, incompatible, and baseline conditions loading at the top in that order. Rather than reflecting interference as an individual difference variable in some manner, these variables probably cohere because of the need to focus on the color of the stimuli and ignore the print, so that at the high end of the latent variable tight focus produces fast reactions, while at the low end loose focus leads to slow reactions.

Further, this focus or concentration factor is not a speed factor in the usual sense of authors who use the term for selective scanning or "perceptual/clerical speed" (Stankov, 1988),

which separates as the third factor of our first analysis. Stankov and Roberts (1997) have made the case that the factorial composition of speed is multi-faceted. This is borne out in our analysis in which four speed factors were obtained from different combinations of speeded reaction tasks, as well as cancellation and Trails-B in the case of the search factor.

It should be noted that the CPT in our battery did not comprise a separate sustain or vigilence factor as it did in the Mirsky studies (Mirsky, 1987; Mirsky et al., 1991), in which CPT accuracy, misses, and RT loaded on a common factor. Rather, in preliminary analyses CPT RT and accuracy did not load on a common factor, and CPT RT remained as part of the focusing RT factor in all analyses. Thus, we have found no evidence for a vigilence factor. One possible explanation is that our five minute CPT was too short to provide a good measure of vigilence, although Kremen et al.(1992) obtained a vigilence factor with an auditory CPT of similar length, but they did not use RT as a measure. Alternatively, the environment of reaction time tasks may have made focusing the dominant component of our CPT, while the CPT was the only RT measure in the Mirsky battery. As previously noted, evidence for a vigilence factor may reguire the use of additional markers for vigilence.

The second RT factor emerging from the Anti and Cue tasks can be viewed as an attention shifting factor, because it involves the ability to control the shifting of attention at the onset of the arrow cues. This control is particularly evident in the incongruous Anti task, which loads highest, where participants have to shift away from the direction of the arrow, and resist the distracting direction of the cue. We term this factor *Shift* (although we have variously called it "filter" for the ability to ignore the cue in the Anti task or "cue" to reflect the endogenous versus exogenous control of attention). Control is most problematic in the peripheral condition in which the cue tends to capture attention exogenously in the direction towards its position, while the shift must go the other way. Thus, at the high end of this dimension volitional control of shifting is high, while at the low end control is compromised by the exogenous capture of attention by the cues. Because of the cued-shift component of these tasks, they would seem to represent an aspect of attention--in contrast to set-shifting (*Sort*) tasks such as the WCS. Supporting this conclusion that *Shift* is attentional in nature and distinct from set-switching, the Anti and Cue tasks never displayed any affinity to the Sort variables in the preliminary analyses of our battery, so indeed "attention shifting" and "set-shifting" appear to be separate underlying processes. It seems possible that this attention *Shift* factor may capture the basic operations of localization and disengagement described by Posner and his colleagues (e.g., Posner & Raichle, 1994).

The third factor was based upon two Search RTs, Cancel and Trail-B. Because the latter two tasks are markers for selective scanning in the previous literature and the Search tasks represent a body of experimental literature on visual search, this is undoubtedly the factor that has been called "Visual Search" in most of the previous studies, which we have variously called *Search* or *Scan*. One important difference from the preceding research is that the search tasks required scanning an array of letters for for a single target, an F among Es, Ls, and Ts, and was a forced-choice task. These search tasks were unlike most of the common markers for *Search* in

prior factor analyses, which required a succession of responses for completion, e.g., Cancel and Trail-B. Thus, the basic search task and search with a popout detractor loaded somewhat higher than cancellation and Trails-B. This may indicate that the best marker for selective attention is the kind of search task used here. The other commonly used markers, such as Cancel and Trails-B, are more complex as indicated by their secondary loadings and include fine motor control as a component, as well as sequencing and set-switching in the case of Trails-B.

The separate factors obtained for search time-based variables and search accuracy variables needs further study. Interestingly, the two types of search-task measures did not load on common latent variables in the preliminary factor analyses of these data. There is some theoretical justification for distinguishing between the accuracy of search (a target-detection factor), representing executive function and the speed of searching representing attention scanning (Zelazo, Carter, Reznick & Frye, 1997). Although the distinction may have support from the experimental literature, there is no inkling of this distinction in the articles reviewed.

Finally, these attention factors of *Focus*, *Shift*, and *Search* are separate from a variety of others ranging from psychomotor skill and short-term memory to the self-report factor. They are also distinct from set-shifting, the one clear executive factor. Several of the nonattention factors also require further study and clarification. The first is the nature of the general accuracy factor. This factor could reflect variation in intentional control from highly deliberate to impulsive. However, as a measure of "carefulness" it could also represent some motivational variable. Second, if the self-report factor represents the tendency to reflect upon cognition, does this indicate the same type of general metacognitive ability which might be characterized as executive monitoring (Zelazo et al., 1997).

Criterion-Task Studies[2]

Identification of latent factor structure for the ASAP battery represents an important first step toward demonstrating that the battery is useful for assessing individual differences in attention skills across dimensions. A second phase of this study is to relate individual differences in the profiles of attention skills with performance on to-be-predicted criterion tasks. As was discussed above, Experiment 2 was also designed to examine the relation between ASAP profiles and performance on several criterion tasks.

Attention Profiles of Demographic Groups

The participants and apparatus for each of these criterion-task studies were described

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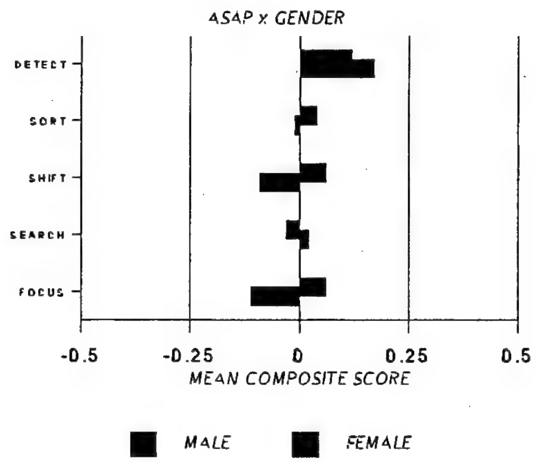
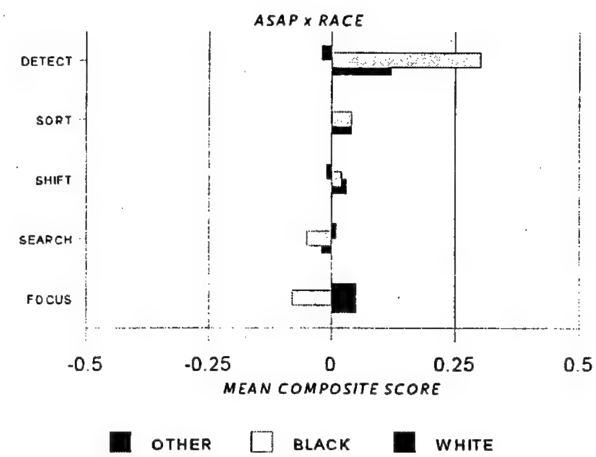
[2] These profiles will be reported as they were discussed at recent professional talks. Subsequent factor analyses have changed the weightings that could be assigned to each task in the computation of composite scores. Final weighted composites will be derived from confirmatory factor analyses (per Fletcher et al., 1996) to be performed later.

above (Experiment 2).

Composite scores were computed by averaging the weighted standardized scores for tasks representing each factor or dimension discussed above. These composite scores were then analyzed as a function of selected grouping variables, using separate independent t-tests for each factor and adjusting the alpha level appropriately for multiple comparisons.. No significant differences[3] were observed for gender or for race across the ASAP dimensions of attention and executive function (see Figures 1 and 2).





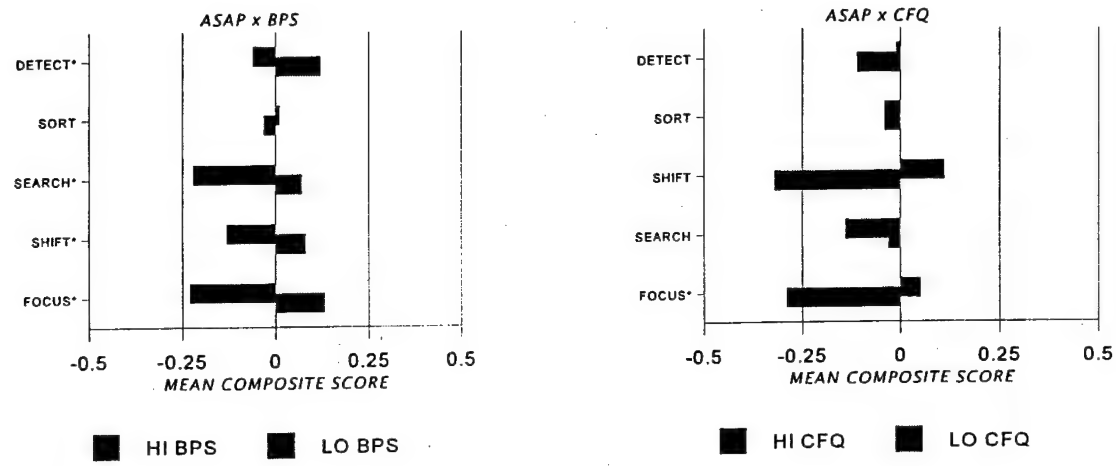
ASAP Profiles and Other Attention Tasks

As was discussed above, the 16-task battery administered to the Air Force recruits included tasks that reflected dimensions of attention and executive function (*Focus*, *Shift*, *Search* or *Scan*, *Sort*, *Detect*), but other tasks that tapped nonattentional cognitive factors (e.g., memory, carefulness). Additionally, several questionnaires (BPS, TLS, CFQ) were included in these tests. These have published data supporting their validity and reliability as self-report tests of attention-related characteristics, despite the fact that they failed to load on a clearly attentional latent variable in our principal components analyses. These tasks provided a ready data-set to examine the relation between attention profiles and other cognitive processes.

Boredom Proneness. We grouped participants from the top and bottom quartiles on the basis of their questionnaire score on the Boredom Proneness Scale (Farmer & Sundberg, 1986). Higher scores on this survey indicate a greater tendency toward boredom. A between-groups analysis of variance revealed reliable differences between boredom-prone participants and those who are not prone to boredom on the *Focus*, *Search*, and *Shift* dimensions of attention ($p < .01$). The executive function of *Detect* also differed significantly between the top and bottom quartile

[3] From Washburn (1998, February)

groups. Thus, individuals who were prone to boredom had reliably worse concentration or focusing skills, slower attention shifting and scanning, and poorer target detection skills. A stepwise regression analysis revealed that a two-factors model (*Focus* + *Search*) predicts small but reliable variance in boredom proneness for the entire sample of 525 participants (multiple $\underline{r}$ = .21, $\underline{p} < .05$). These differences can be seen in Figure 3.



Cognitive Failure[4]. The Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982) was designed to quantify the tendency to make action slips and similar errors. Participants from the upper and lower quartiles were grouped, and attention profiles were analyzed as a function of these groups. Reliable differences were observed for the *Focus* and *Shift* dimensions ($\underline{p} < .01$). Interestingly, individuals who reported frequent cognitive failures were characterized by better focusing and shifting skills than people in the "rare cognitive failures group." Only *Focus* predicted reliable variability in the 525 CFQ scores (multiple $\underline{r}$ = .19, $\underline{p} < .05$). Again, better concentration was associated with more cognitive failures. As might be inferred from these analyses, CFQ scores correlated significantly and negatively with BPS ($\underline{r} = -.45$, $\underline{p} < .01$).

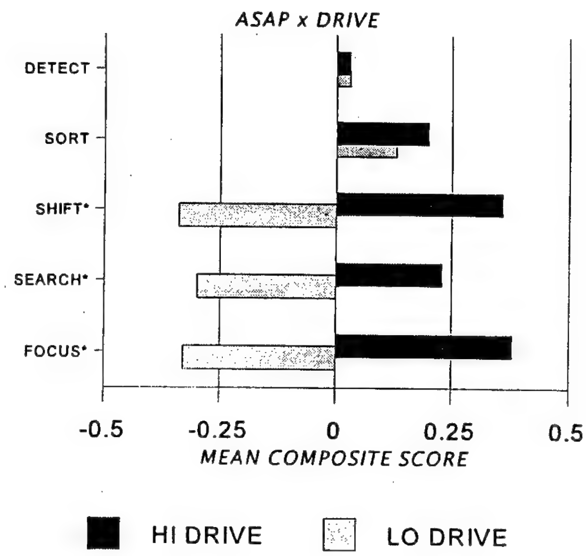
DRIVESIM Test of Situation Awareness[5]

A test of situation awareness (called DRIVESIM) was administered to 135 of the Air Force recruits who completed the ASAP battery. This sample had an age range of 17 to 30 years (mean = 20.19 years) and included 40 females. The DRIVESIM task required participants to respond to a series of driving-emergency scenarios and then to respond to numerous probes about the locations and behaviors of vehicles in the scene. A composite DRIVESIM score was used to characterize individual differences in situation awareness ability, and participants were grouped

[4] From Washburn, D. A. & Putney, R. T. (1998, August).

[5] From Washburn, Putney, Tirre, Gugerty, & Robbins (1997, October)

on the basis of this score into HI DRIVE (top quartile) and LO DRIVE (bottom quartile) groups. Across the entire sample, DRIVESIM performance was reliably predicted by a one-variable (*Focus*) stepwise model ($r = .36$, $p < .05$). Restricting the sample to the HI DRIVE and LO DRIVE groups, one can account for over 31% of the DRIVESIM variance with the attention factors *Focus* and *Shift* (multiple $r = .56$, $p < .05$). A mixed-model analysis of variance, with attention profiles analyzed across DRIVESIM quartile groups, revealed reliable differences for the dimensions of *Focus*, *Shift*, and *Search* ($p < .01$). Individuals characterized by good situation awareness (as assessed by DRIVESIM) also tend to have good concentration, searching, and controlled attention shifting skills.



Analog Flight Control Task[6]

An analog flight control (AFC) task was administered to 168 of the Air Force recruits who completed the ASAP tasks in Experiment 2. The task requires simultaneous monitoring and responding both to speeded and to unspeeded probes. For example, participants must maintain pitch, roll and yaw orientation as revealed by gauges in the middle of the computer screen. However, they must also monitor oil temperature and oil pressure gauges and respond to conditions indicated by these gauges quickly. Finally, a series of true/false questions appear in an upper window on the computer screen. These questions require fast and accurate responses. Thus, the AFC task represents good task of high workload, multiple-concurrent-task performance. The relation between individual differences on this task and those revealed by ASAP are particularly interesting because no "dual" or "share" factor has been found in studies of the dimensions of attention, including our own.

Composite scores were computed for flight orientation (error in pitch, roll and yaw) and for oil monitoring (response time and accuracy of responding to oil temperature and pressure gauges). For each of these composite scores, groups were split by quartile and analyzed against ASAP attention profiles. Reliable differences were observed between the best and poorest participants in flight orientation only for the *Focus* dimension ($p < .01$). About 11% of the variance in the flight orientation composite was associated with *Focus* ($r = .33$, $p, < .05$).

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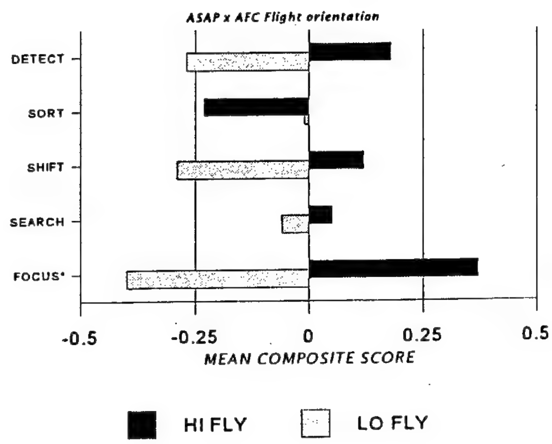
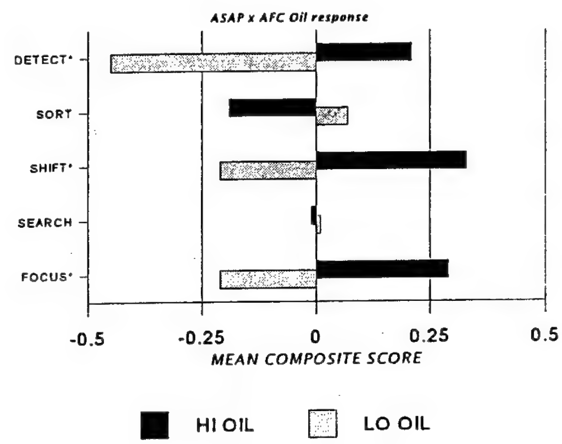
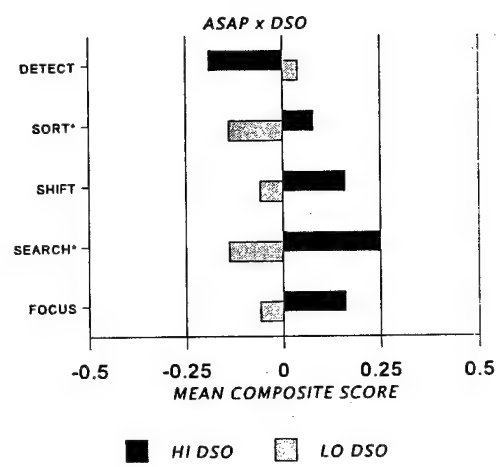
[6] From Washburn, Putney & Tirre (1998, November)

The *Focus* factor also varied reliably between the top and bottom performers in oil monitoring, as did *Detect* and *Shift* factors ($p < .05$). The oil composite was best predicted by the *Detect* composite variable from ASAP ($r = .20$, $p < .05$). In summary, individuals who responded quickly and accurately to speeded, concurrent probes also tend to have strong concentration, attention shifting, and accurate target detection skills. Those who concentrate or focus well also tend to perform well in maintaining flight orientation.





Defensive Strategic Operations (DSO) Task[7]



A defensive strategy training task was administered to 186 of the Air Force recruits who completed ASAP in Experiment 2. This is a complex task requiring substantial new learning of the rules of the game and the strategies that result in good scores. The task yields a score that reflects the effectiveness of defensive maneuvers. A composite score was calculated from the repeated training trials of the DSO task. People in the HI DSO group (top quartile) were compared with people in the LO DSO group (bottom quartile) across ASAP dimensions of attention and executive function. Poor DSO performers were characterized by significantly lower *Sort* and *Search* skills ($p < .05$), and the two-factor regression model comprised of these factors accounted for small but significant variability across the 186 participants (multiple $r = .37$, $p < .05$). Thus, people who performed poorly on DSO tended to make more perseverative or other set-switching errors and to manifest slower attention scanning than did people who performed relatively well on DSO.

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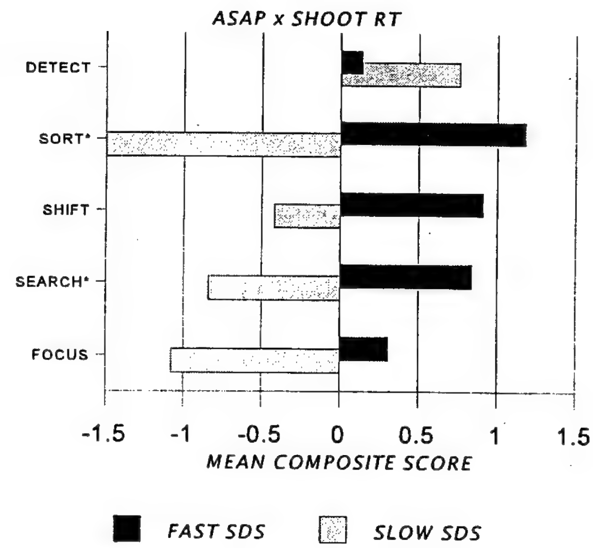
[7] From Washburn (1998, February)

Shoot/Don't-Shoot Judgments[8].

At the Center of Excellence for Research on Training at Morris Brown College, we also conduct research that requires speeded judgments. Using a firearms training simulator, students are tested on scenarios that require rapid and accurate shoot/don't-shoot judgments. We tested 30 student volunteers on a series of videotaped scenes. Each scenario was played on a cinema screen, to which students responded with a laser pointer. Students were grouped into quartiles based on signal detection measures (d' and bias) and on the basis of response speed. No reliable differences were obtained across ASAP dimensions for groups defined by bias and sensitivity measures. However, shoot/don't-shoot response time was reliably predicted by a regression model of *Search* and *Sort* (multiple $r = .84$, $p < .01$). The fast decision group tended to manifest relatively high rates of attention scanning and relatively few perseverations or other sorting errors. In contrast, the slow-decision group were reliably lower in searching and set-switching skill.



General Discussion

These data are rich and interesting, as is indicated by the number of presentations that the studies have yielded thus far. Indeed, analyses of these data continues, even as new studies are being performed using the ASAP battery. Although all of the research defined in the contract has been completed, numerous new issues remain for this experiment. We will conduct second-order and confirmatory factor analyses on the Experiment 2 data, and continue the re-analysis of Experiment 1 data. We will also relate ASAP profiles to other measures, particularly those that reflect fluid intelligence. Finally, we have piloted a short version of ASAP and have submitted a proposal to use the battery in studies of the development of attention and the diagnosis of attention deficit disorders in adults and children.

Additional modifications of the ASAP battery are also needed to improve the predictive utility of the battery. Although reliable differences and correlations have been reported here, the magnitude of these relationships is smaller than was hoped. Of course, ASAP was designed

[8] From Washburn & Greene (1996, November); Washburn, Greene & Putney (1997, November)

only to provide an automated assessment tool for individual differences in attention, and streamlining the battery has resulted in the removal of many tasks and several factors that reflect other aspects of cognition. It remains important to determine whether the unique contribution of individual differences in attention and executive function in the variance of tasks that reflect the coordination of many aspects of cognition.

ASAP Presentations

Washburn, D. A., & Putney, D. A. (1999, June). Attention Profiles of Working Memory. Paper at the meeting of the American Psychological Society, Denver, CO.

Putney, R. T., & Washburn, D. A. (1999, April). Individual Differences in the Dimensions of Attention. Paper at the meeting of the Southern Society for Philosophy and Psychology, Louisville, KY.

Washburn, D. A., & Putney, R. T., (1999, April). Individual Differences in Time Estimation and Concentration. Paper at the meeting of the Southern Society for Philosophy and Psychology, Louisville, KY.

Raby, P. R., Washburn, D. A., & Putney, R. T. (1999, March). Attention Profiles and Vigilance Performance. Poster presented at the meeting of the Southeastern Psychological Association, Savannah, GA.

Washburn, D. A. (1998, November). Chronometric and Pupillometric Indices of Planning. Paper at the meeting of the Psychonomic Society, Dallas, TX.

Washburn, D. A., Putney, R. T., & Tirre, W. (1998, November). Attention Profiles for Speeded and Unspeeded Decision Making. Poster at the meeting of the Society for Judgment and Decision Making, Dallas, TX.

Washburn, D. A., & Putney, R. T. (1998, August). Attention Profiles of Boredom Proneness and Cognitive Failure. Poster at the meeting of the American Psychological Association, San Francisco, CA.

Putney, R. T., & Washburn, D. A. (1998, April). The Inhibitory Effects of Incompatible Cuing on Choice Reaction Time. Paper at the meeting of the Southern Society for Philosophy and Psychology, New Orleans, LA.

Raby, P. R., Washburn, D. A., & Washburn, D. A. (1998, April). Attention Profiles: States or Traits. Paper at the meeting of the Southern Society for Philosophy and Psychology, New Orleans, LA.

Harris, S. K., Greene, H. H., Washburn, D. A. (1998, March). Attention in Shoot/Don't-Shoot Decision Making: Gender Differences. Poster at the meeting of the Southeastern Psychological Association, Mobile AL.

Washburn, D.A. (1988, February). Individual and Group Differences in Attention Profiles. Invited address at the psychology colloquium series, Georgia Institute of Technology, Atlanta, GA.

Washburn, D. A., Greene, H. H., & Putney, R. T. (1997, November). Individual Differences in Attention and Shoot/Don't-Shoot Skills. Poster at the meeting of the Society for Judgment and Decision Making, Philadelphia, PA.

Washburn, D. A., & Putney, R. T. (1997, November). Pop-out Distractors in Visual Search. Paper at the meeting of the Psychonomics Society, Philadelphia, PA.

Putney, R. T., & Washburn, D. A. (1997, April). The Factors of Attention: a "Meta-analysis". Paper presented at the meeting of the Southeastern Psychological Association, Atlanta, GA.

Washburn, D. A., & Putney, R. T. (1997, October). Individual Differences in Attention Profiles. Poster at "The Future of Learning and Individual Differences Research: Processes, Traits, and Content" conference, Minneapolis, MN.

Washburn, D. A., Putney, R. T., Tirre, W. C., Gugerty, L. J., & Robbins, R. L. (1997, October). Individual Differences in Attention and Situation Awareness in Driving. Poster at "The Future of Learning and Individual Differences Research: Processes, Traits, and Content" conference, Minneapolis, MN.

Washburn, D. A., & Greene, H. H. (1996, November). Attentional Factors in Shoot/don't-shoot Decision Making. Poster presented at the annual meeting of the Society for Judgment and Decision Making, Chicago, IL.

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Table 1. Attention: Meanings, metaphors, phenomena, and related processes

concentration	filter	cocktail party	perception
selection	bottleneck	Stroop	working memory
mental effort	attenuator	attn capture	rehearsal
watchkeeping	spotlight	cost/benefit cue	learning
arousal	gate	joint attention	consciousness
capacity	glue	automaticity	executive function
activation	bulletin board	set-size effect	psychological well-being
search	sleep/awake	pop-out	apperception
set shifting	resources	illusory conjunctions	conditioning
inhibition	constraint	stimulus movement	recall
carefulness	satisfaction network	priming	communication
alertness	beam	signal detection	response selection
workload	amplifier	hyperactivity	
vigilance		surprise	
switching		complementarity	

Table 2. Selected factor analytic studies of attention and executive function

AUTHORS / YEAR	FACTOR NAMES / DEFINING TASKS				
Whittenborn (1943)	Concentration		Search		
Sack & Rice (1974)	Resistance to distraction		Attention shifting		Selectivity
Stankov (1988)	Concentration		Attentional flexibility		Search/ Perceptual speed
Mirsky (1987)	Focus/ execute	Sustain	Shift	Encode	
Mirsky, Anthony, Duncan, Ahearn, & Kellam (1991)	Focus/ execute	Sustain	Shift	Encode	
Kremen, Seidman, Faraone, Pepple, Tsuang (1992)	Focus/ execute	Sustain	Shift	Encode	
Pogge, Stokes, & Harvey (1994)	Focus/ execute	Sustain	Shift	Encode	
Shute & Huertas (1990)	Category test, Trails B, WCS, Cog Devel. Level Assess	Trials A, WAIS digit symbol	Selective attention ("shifting")	Time estimation	
Welsh, Pennington, & Grossier (1991)	Verbal fluency, visual search, category exemplar production		WCS, MFFT		TOH disk-transfer task 3, 4
Daigneault, Braün, & Whitaker (1992)	SOPT, recency	WCS, Trails B	Stroop, verbal fluency	Porteus Maze Test	
Dempster, Corkill, & Jacobi (1996)	WCS		PAL, paired associates		General ability, Stroop, Ravens, Interference

Table 3. ASSESSMENT SOFTWARE FOR ATTENTION PROFILES (asap) BATTERY

TASK NAME	DESCRIPTION	VARIABLES
RT-1	Simple response-time task (click the button when an F appears)	RT
RT-2	Choice response-time task (F=button one, E=button 2)	RT, %, ΔRT
CPT	Continuous Performance Task (click the button, each F, 6-min vigil)	RT, %, deviation
SEARCH	Visual Search (F embedded in E, L, T; F in O, C, Q; F in E, O, T)	set size slope, %
STROOP	Stroop color-word task (baseline, congruous, incongruous)	RT, %, ΔRT
CUE	Central and peripheral valid cuing paradigm	RT, %, ΔRT, Δ%
ANTI	Central and peripheral in-valid cuing paradigm	RT, %, ΔRT, Δ%
COMPARE	Rapid presentation of two streams of letters, with match/nonmatch judgment	RT, %, slope
TRAILS	Click on an interdigitated series of letters and numbers	RT
SORT	Card Sort-type task requiring set switching	%, sorts, perseverations
CANCEL	Letter cancellation task	# cancels
TRACK	Pursuit tracking with or without concurrent memory task	error, Δerror
MEM	Serial probe recognition with or without concurrent tracking	RT, %, ΔRT, Δ%
BPS	Boredom Proneness Scale	score
CFQ	Cognitive Failures Questionnaire	score
TLX	NASA Task Load Index	score

Table 4: RT Variables

VARIABLE	F1	F2	F3	F4	F5
STROOP congr. RT	.82				
STROOP incongr. RT	.80				
STROOP baseline RT	.80				
RT-2 mean RT	.68				
RT-1 mean RT	.57				
CPT mean RT	.56				
COMPARE mean RT	.50				
ANTI perif RT		.86			
ANTI central RT		.83			
CUE perif RT	.54	.64			
CUE central RT	.54	.56			
SEARCH1 RT			.76		
SEARCH3 RT			.74		
CANCEL #letters			.62		
TRAILS-B RT			.52		
TRACK mean error				.83	
DUAL TRACK error				.83	
DUAL MEMORY RT					.78
MEMORY RT					.72

Table 5: Accuracy Variables

VARIABLE	F1	F2	F3	F4	-
RT-2 %	.72				
ANTI perif %	.70				
CUE central%	.59				
ANTI central %	.59				
CUE baseline %	.58				
CUE perif %	.56				
COMPARE %	.53				
SORT reversals		.90			
SORT %		.71			
SORT perseveration		57			
DUAL MEM %			.84		
MEMORY %			.83		
CFQ				.81	
BPS				.81	
TLX					
SEARCH1 %					.82
SEARCH3 %					.71

TASK NAME	BRIEF DESCRIPTION	STATUS
RT-1	Simple response time task	2
RT-2	Choice response time task	1
CPT	Continuous Performance Task	2
SEARCH1	Visual search for F embedded in arrays of E & T	1
SEARCH2	Visual search for 0 embedded in arrays of E & T	2
SEARCH3	Visual search for F embedded in E, T, & O	1
STROOP1	Numerical version of Stroop task	4
STROOP3	Stroop color-word task	1
SORT1	One-dimension-shift "card sort" task	3
SORT2	Three-dimension-shift "card sort" task	1
INHIB	Response inhibition task	3
RSVP	Attention scanning/comparison task	2
FIELD	Attention field-of-focus task	5
SME	Discrimination learning with moving stimuli	5
CUE	Valid central and peripheral cuing task	1
ANTI	Anti-saccade task with non-valid cues	1
DETECT	Signal detection task	5
TRAILS A	Standard neuropsychology test requiring scanning and sequencing	4
TRAILS B	Sequence in Trails-A must be alternated with a second sequence	1
MROT	Mental rotation task used in SWITCH	3
RNJ	Relative numerousness judgments used in SWITCH	3
SWITCH	Alternate randomly between two different tasks	3
TRACK7	Pursuit tracking used alone and in DUAL	1
MEM	Serial probe recognition used alone and in DUAL	1
DUAL	Concurrent tracking and memory tasks	1

SELTR	Tracking version of selective looking task	3
EST	Time estimation task	3
TLX	NASA Task Load Index questionnaire	1
CFQ	Cognitive Failures Questionnaire	1
BPS	Boredom Proneness Scale questionnaire	2
ADD	Attention Deficit Disorder symptom checklist	4
PRP	Psychological Refractory Period paradigm	4

Status codes:
1 = Retained in current battery.
2 = Eliminated from final battery as a result of Experiment 2 analyses.
3 = Eliminated from battery after Experiment 1 analyses.
4 = Eliminated from battery after pilot studies for statistical or empirical reasons (e.g., poor validity, reliability, or sensitivity).
5 = Eliminated from battery after pilot studies for practical reasons (e.g., too difficult to administer or understand, too many trials required; overlap with other tasks).